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MIRROR MODE STRUCTURES AND POSSIBLE ELF PLASMA WAVE INSTABILITIES IN THE GIACOBINI-ZINNER MAGNETOSHEATH

by

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Abstract

We show evidence for mirror mode structures at comet Giacobini-Zinner. These structures occur just adjacent to the magnetic tail, indicating that magnetic field draping is the mechanism for instability. If these field lines eventually become part of the low magnetic tail β, then the further depletion of plasma will lead to field-aligned blobs of high beta plasma going in the antisunward direction (rays with embedded quasiperiodic structures?). Both electrostatic and electromagnetic waves are detected in relation with the mirror mode structures.

INTRODUCTION

Mirror mode structures are generated by plasma pressure anisotropies where $\beta_\perp/\beta_\| > 1 + 1/\beta_\perp$ (Hasegawa, 1969; 1975; Patel et al., 1983; Migliuolo, 1986; Price. et al., 1986; Price, 1989; Hasegawa and Chen, 1989; see also Southwood and Kivelson, 1993; Kivelson and Southwood, 1996). In the above, the plasma β is 8π nkT/B^2, where T is temperature, B the ambient magnetic field, and n the ion number density. Such ion distributions can be generated by heating across quasiperpendicular shocks (Kennel and Sagdeev, 1967) and from the Zwan-Wolf (1976) magnetic field line draping effect (Tsurutani et al., 1982). These mirror mode structures are traditionally expected just downstream of shocks (Lee et al., 1988) and near planetary and cometary magnetopauses.

Mirror mode structures have been well documented in the magnetosheaths of the Earth, Jupiter and Saturn (Tsurutani et. al., 1982, 1983; Violante et al., 1995; Erdös and Balogh, 1996, Bavassano-Cattaneo et al., 1998; see the last reference for nearly a complete list of works on this subject), and in interplanetary space at solar wind stream-stream interfaces (Tsurutani et al., 1992). Mirror modes have also been detected in the sheath of comet Halley (Yeroshenko et al., 1986; Russell et al., 1987, Mazelle et al., 1991). The purpose of this paper is to present the first observation of mirror mode structures at comet Giacobini-Zinner.

The MHD (macroscopic) mirror mode instability can also couple to several microscopic instabilities. Electromagnetic (ELF) whistler mode waves and electrostatic (VLF) ion acoustic emissions have both been detected in association with mirror waves. Electromagnetic lion roars (Smith and Tsurutani, 1976) can be driven unstable by the high β, low-field plasma portions of the mirror structures (Thorne and Tsurutani, 1981; Tsurutani et al., 1982; Lee, et al., 1987; Zhang et al., 1998) as an absolute instability (Moreira, 1983). (See Zhang et al. (1998) for a current update on lion roar observations). The instability is caused by a local decrease in the critical energy, E_c, allowing cyclotron resonance with a great portion of the thermal electron population. Electrostatic ion acoustic waves are generated in the low β high field plasma regions of mirror mode structures (Anderson et al., 1982; Gallagher et al., 1985). A second purpose of this paper is to explore ELF waves associated with comet Giacobini-Zinner mirror mode high β and low β regions.

RESULTS

Figure 1 is a composite plasma and magnetic field data plot. The electron temperature and density values are given in the top two panels, respectively. The magnetic field components in aberrated cometary solar ecliptic coordinates (i.e., x' is anti-parallel to the upstream solar wind velocity vector; Slavin et al., 1986) are displayed in the next three panels. The bottom panel contains the magnetic pressure and the plasma pressure (represented by 6 times the electron pressure; see Slavin et al., 1986). The Los Alamos ion instrumentation unfortunately quit functioning earlier in the mission and the energetic ion flux temporal resolution was too low to be useful for this type of high time resolution study.

In Figure 1, it can be noted that although there are fluctuations in the B_y and B_z components, the field is relatively constant in direction but with major magnitude (pressure) variations after G-Z exited the magnetotail at 1107:40 UT. The plasma pressure is observed to have peak values where the field has minimum values. It can be noted that there are about 6 major magnetic field and plasma oscillations over the 10 minutes displayed. In each oscillation, the field and plasma are out-of-phase. The oscillation period varies from ~ 40 seconds at the beginning of the interval to about ~ 60 seconds at the end of the interval. Over this interval, the magnetic field decreases from ~ 30 nT to ~15-20 nT as ICE moves further from the sun-comet line. Assuming these structures are more or less stationary relative to the comet nucleus ($V \equiv 30$ km/s in the cometary ionosheath adjacent to the tail), and the ICE is traveling through the structure, the scale size of the structure is ~ 3 x 10^3 km. Assuming an average ambient magnetic field strength of 20 nT, and an ion velocity of ~30 km/s, this scale corresponds to ~25 $r_{H_2O^+}$.

Figure 2 gives the electric field amplitude of the plasma waves in the frequency range from 17 Hz to 100 kHz. Each channel has a frequency bandwidth of 0.5 f_{center}. The amplitude is given on a relative logarithmic scale. The ambient magnetic field magnitude is plotted in the bottom panel for reference. In the top half of the figures, we have added the value of the local electron gyrofrequency as a reference. Vertical dashed lines and shading have been added in to help the reader visualize the correlation/and lack of correlation between the VLF/ELF plasma waves and the plasma and field structures.

We believe that there may be two different ELF modes present at frequencies < 562 Hz: a low frequency mode detected primarily at and below f = 100 Hz and a broadband sporadic mode that extends to higher frequencies. The lower frequency band is most easily observed in the 100 and

56.2 Hz channels, and the broadband bursts in the 311 and 562 Hz frequency channels. The latter is more noticeable where there is less power associated with the lower frequency mode, or at frequencies above 178 Hz. Examples of the lower frequency (56.2 and 100 Hz) mode can be noted at 1108:00 to 1108:50 UT, 1109:50 to 1110:20 UT, 1113:20 to 1114:30 UT and 1115:00 to 1115:50 UT. All of the above ELF wave enhancements occur in the magnetic field decreases. In contrast, the higher frequency (562 Hz) emissions are detected at or near peaks in B magnitude. Examples are found at ~1106:10 UT, 1107:30 UT, 1111:00 UT, 1112:45 UT and 1114:50 UT.

The presence of these two modes and their dependence on the magnetic field magnitude (and β) are similar to the case of the earth's magnetosheath. Anderson et al. (1982) have noted that "festoon-shaped" electrostatic emissions occur during high field (low β) regions and the electromagnetic lion roar emissions in high β regions. This is shown as Figure 3. The analogy is nearly exact (even if the plasma emissions are quite weak in the Giacobini-Zinner example.)

DISCUSSION

Many of the mirror mode field and plasma characteristics of the event from 1106 to 1116 UT are very similar to that at the Earth. The magnetic and plasma pressure are out-of-phase and the total pressure is more or less constant.

At 1108 UT, ICE was ~11,000 km from the comet nucleus. The magnetic field orientation on average was close to orthogonal to the solar direction. At these distances, the neutral density is ~ 1.5×10^4 cm^{-3} sec^{-1} (assuming $Q = 2 \times 10^{28}$ mol./sec). The low local ionosheath velocity of ~ 30 km s^{-1} (Bame et al., 1986), implies a maximum perpendicular pressure per ion of 1.4×10^{-10} dynes. The perpendicular pressure of the pickup ions is thus ~ 2×10^{-12} dynes cm^{-2} Δt, where Δt is the length of time of ion accumulation. Because the velocity increase is much steeper than the cometary neutral density decrease with increasing distance, the growth times are higher further from the magnetic tail. The mirror mode should go unstable in time scales of ~ 10^3 sec or $\cong$ 20 min. This is irrespective of plasma pressure anisotropies generated by shock heating of the upstream plasma or by the field line draping. The latter effects will increase the anisotropy and the rate of instability.

The gyroradius of a 30 km s^{-1} H_2O^+ ion in a ~ 20 nT field is $\cong$ 100 km, so the scale size of the mirror structures are $\cong$ 25 times the (local) heavy ion gyroradius. This is comparable to the scale of the mirror waves in the earth's magnetosheath in comparison to the dominant ion present there (protons), $\lambda_{\perp} \cong 20\text{-}30\ r_p$ (Tsurutani et al., 1982).

FINAL COMMENTS

The mirror mode structures were detected just adjacent to the magnetotail (or magnetic field pileup region) boundary. This is similar to the results of Mazelle et al. (1991) at comet Halley. Thus field line draping around the comet is the mechanism that leads to the creation of the pressure anisotropy causing instability. It is noted, however, that there are no mirror mode structures on the inbound pass.

The role of mirror mode structures in the formation of the magnetic tail is unclear. The structures (see Price et al. 1986 for a schematic) would consist of high and low β patches along field lines. The plasma clumps (high β regions) must eventually flow in the antisunward direction along the magnetic fields if these magnetic fields are to become part of the tail. It is possible that these evolved mirror mode structures become rays as discussed by (Russell et al., 1987). However, if this is the case, then the elongated rays close to the comet head should have definite density variation. High spatial resolution images should be able to say if this is the case or not.

Finally, we should comment that the presence of the intense electrostatic emissions can very efficiently accelerate both ions and electrons. Buti and Lakhina (1987) have explored the consequences of stochastic acceleration of ions to energies above solar wind pickups. The same process can be effective in accelerating electrons. The consequences for these processes and the eventual energy sink is yet to be explored.

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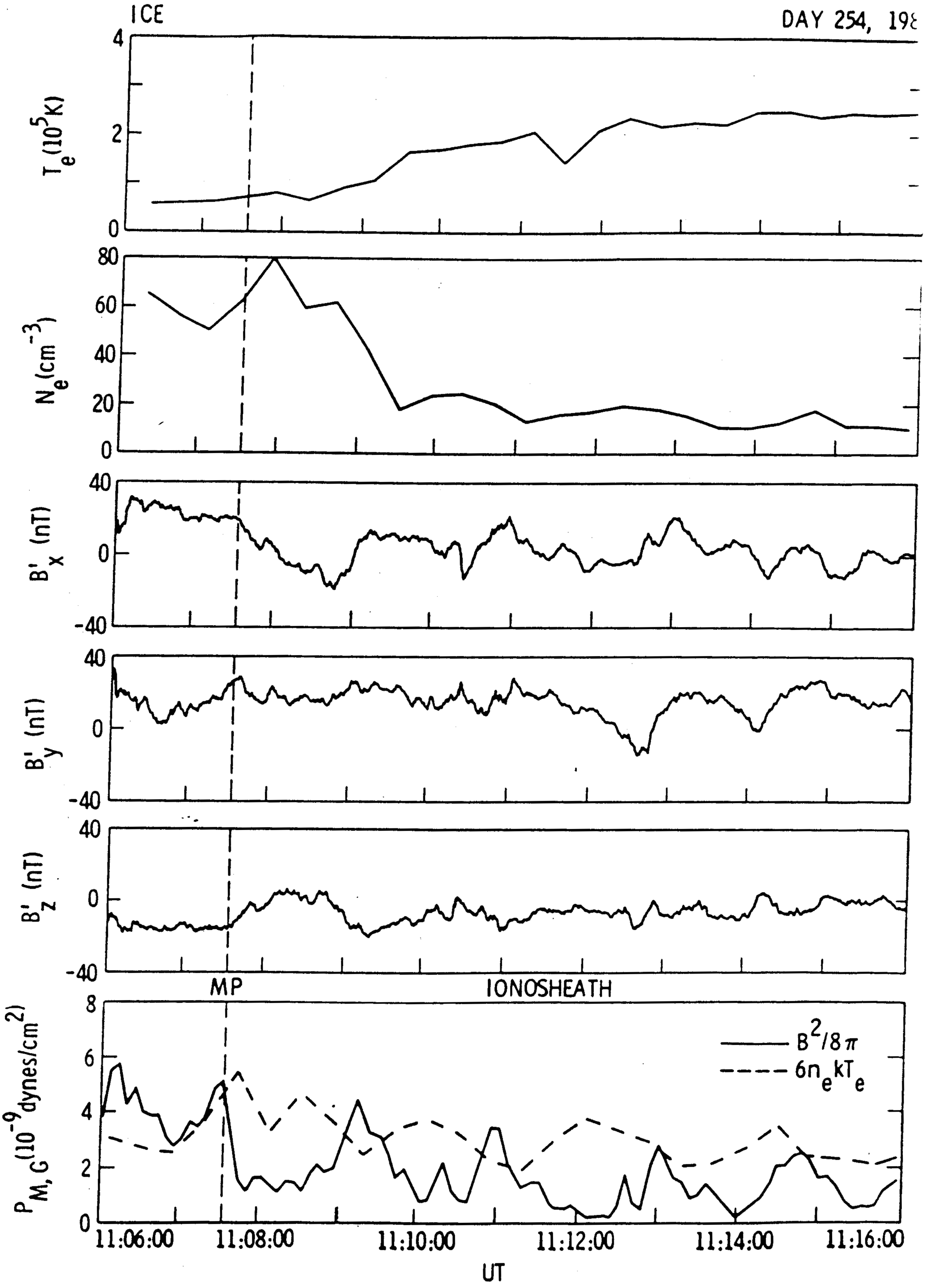
FIGURE CAPTIONS

Figure 1. Mirror mode structures in the outbound pass of comet Giacobini-Zinner (bottom panel).

Figure 2. The electric component of ELF/VLF waves related to the mirror modes.

Figure 3. Electromagnetic lion roars and electrostatic emission associated with mirror modes in the Earth's magnetosheath. Taken from Anderson et al. 1982 (their Figure 2).



ICE
DAY 254, 19ε
$T_e (10^5 K)$
$N_e (cm^{-3})$
B'_x (nT)
B'_y (nT)
B'_z (nT)
MP
IONOSHEATH
$P_{M,G} (10^{-9} dynes/cm^2)$
$B^2/8\pi$
$6n_e kT_e$
11:06:00
11:08:00
11:10:00
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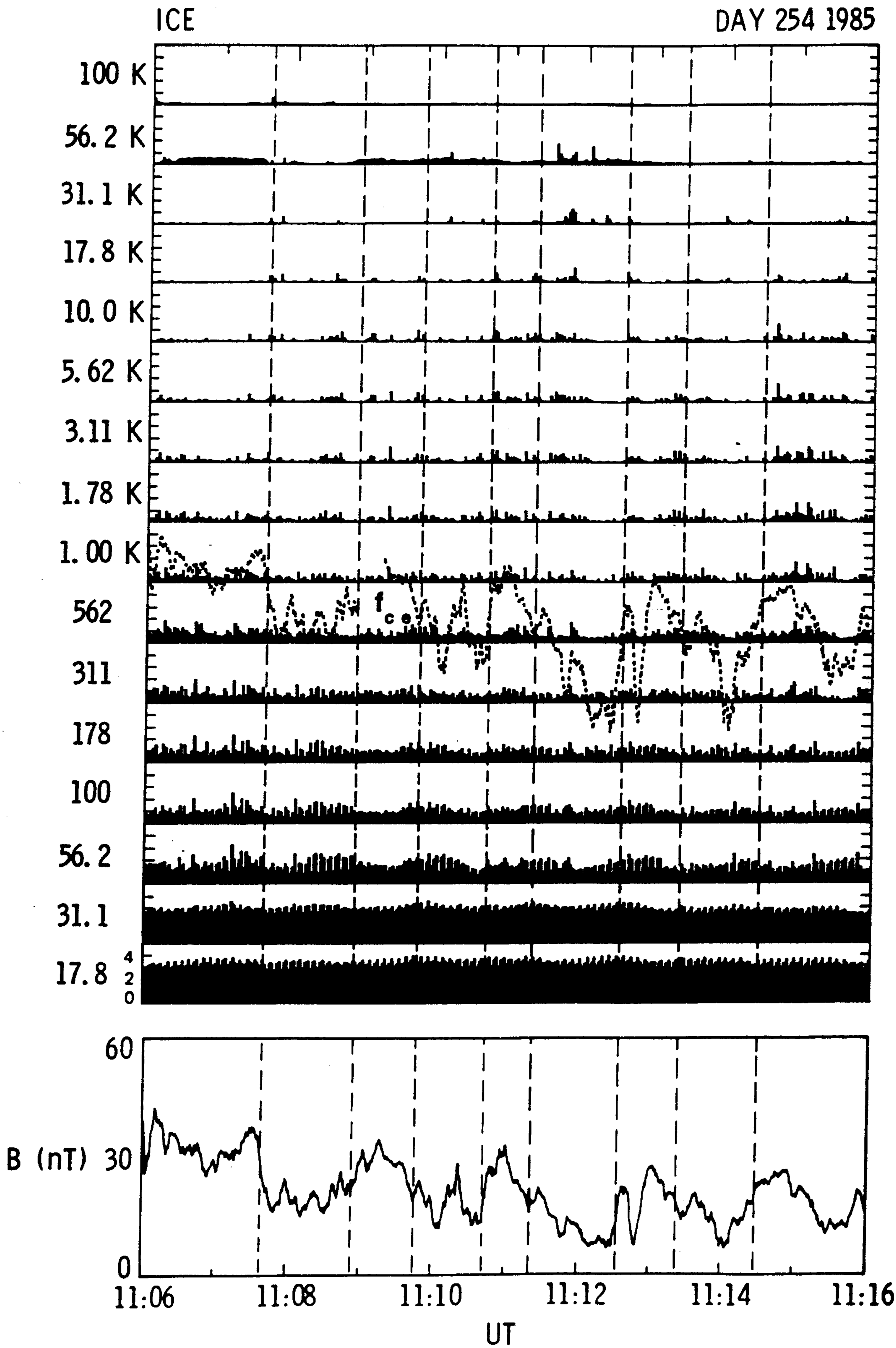
11:14:00
11:16:00
UT


ICE
DAY 254 1985
100 K
56.2 K
31.1 K
17.8 K
10.0 K
5.62 K
3.11 K
1.78 K
1.00 K
562
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178
100
56.2
31.1
17.8
4
2
0
f_{ce}
60
B (nT) 30
0
11:06
11:08
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11:12
11:14
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UT

ISEE 1 NOVEMBER 8, 1977 DAY 312
NOMINAL MAGNETOSHEATH